Recent Upgrades of the Optical Synchronization System at FLASH

Jost Müller on behalf of the LbSync team
Hamburg, 5. February 2019
Outline

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• MicroTCA.4

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• laser synchronization
• (BAM)

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Introduction
LbSync Activities at DESY

Group Structure and Historical Overview

LbSync team: currently 7 members

- 2004: first developments started in collaboration with MIT, hosted in FLA group,
- **2008**: LbSync operation at FLASH started
- 2010: project moved to MSK
- 2017: first experiments at XFEL using optical synchronization
- **2018**: renewal of FLASH LbSync system
- 2018: SINBAD injector laser synchronization
- 2019: finish installation of XFEL LbSync system
- **2020**: finish renewal of FLASH LbSync system
- 2020+: installation LbSync at SINBAD

6 LbSync labs
23 laser labs of other groups with LbSync systems
FLASH Optical Synchronization Upgrades 2018+

Why Upgrading?

Performance
- MZI-based MLO synchronization: **jitter 30 fs → 3 fs, drift stability**
- single-mode fiber (SMF) replaced by polarization-maintaining (PMF)
  - **jitter 3 fs → 0.5 fs**
  - enhanced drift stability
- MicroTCA.4-based system
- laser synchronization: **jitter 15 fs → 5 fs**

Space
- old structure (optical table, infrastructure, etc) allowed **only 8 links**
- **24 optical links required** including potential future upgrades

Discontinued Components
- VME system
- migration of all control electronics to MicroTCA.4

Reliability & Maintainability
- same setup like at the XFEL
- software / firmware
Optical Reference & Distribution
FLASH Optical Synchronization System

End stations
- 3 RF stations (RF-resynchronization)
- 8 bunch arrival time monitors (BAM)
- 12 laser systems (injector, seed, pump-probe, experiment)
Main Synchronization Laboratory XFEL

Infrastructure

• strict separation of optics, electronics, general working space

• **no electronics in optics part** → no heat sources, EMI, vibration

• environmental stability → dT < 0.1K / dRH < 5%

• EMI → **proper grounding** (single grounding point), optical cables used if possible, separate potential EMI sources from critical systems

• acoustics & vibrations → **optics part acoustically isolated**

• UPS for operation-critical systems

main optical table at XFEL, UG5
Master Laser Oscillator (MLO)

The Main Optical Reference

Oscillator

- commercial (NKT, former Onefive)
- SESAM-based, passively mode-locked
- ultra-low phase noise, Erbium, 1550 nm
- 24/7 operation

Synchronization

- laser-to-RF based, low-noise (~3 fs), low-drift, amplitude insensitive locking scheme

Redundancy

- two similar laser oscillators
- both synchronized all the time, individual setups, identical timing
- fast switching of active source: no link lock lost, timing preserved
Free-Space Distribution

Laser Beam Distribution for 24 Fiber Link Stabilization Units

- **SuperInvar optical table**
  - thermal expansion coefficient ~1 fs/m/K
  - no bimetallic effects (sandwich)
- second optical table for motorized delay lines
- space for 24 link stabilization units
  - identical path lengths, symmetric setup
- 8 link stabilization units with 4 ns optical delay
  - arbitrary timing possible for BAM operation
- table completely covered and environmentally stable
  - ≪ 0.1 K rms temperature stability
- online diagnostics: power, pointing, temperature (air, table, each station, MLOs), humidity

CAD drawing courtesy of C. Sydlo
LSU: Principle of Operation

Measurement

- balanced optical cross-correlation
- insensitive to laser pulse amplitude fluctuations
- typical slope 5 mV/fs
- polarization-maintaining fibers to mitigate PMD-related timing errors

Detection and control

- self-built, low noise balanced photodetector BPD (0.1 mV rms in 1 MHz bandwidth)
- MTCA.4: digitizer, FPGA-based controller, piezo- and motor-drivers

Actuators

- piezo-based fiber stretcher (~3.5 ps range, fast)
- optical delay line (4 ns, slow), self-built
Link Stabilization Units (LSU)

Measurement Results

Link-Stabilization-Units: Out-of-loop measurement

Performance

• jitter (rms) < 500 as
• drift: 3.3 fs / 24 h
• observed drift compensation at XFEL: up to 200 ps/km!
MicroTCA.4 for LbSync

- **DRTM-DWC10**: 10 channel RF down-converter for laser synchronization
- **DRTM-LASY**: dedicated laser synchronization board
- **DRTM-AD84**: ADC board for link signal detection
- **DRTM-PZT4**: 4-Ch, ±100V piezo driver for link & laser synchronization
- **DAMC-FMC20**: FMC carrier board laser synchronization
- **DAMC-FMC25**: FMC carrier / FPGA link synchronization
- **SIS8300L2**: 10-Ch 125 MS/s 16-bit ADC, 2x 16-bit DACs, Virtex FPGA
- **DFMC-MD22**: 2-Ch, encoder
- **DFMC-UNIIO**: universal I/O, MLO/shutter control
- **DFMC-AD16**
- **X2TIMER**
End Stations
The Optical Reference Module (Refm-Opt)

Femtosecond RF Reference Phase Stabilization

- uses a stabilized fiberlink from the pulsed optical synchronization system as reference
- employs a drift-free L2RF phase detector
- locally re-synchronizes the 1.3 GHz RF reference with femtosecond precision in a PLL
- phase-stabilized Wilkinson splitter to provide multiple outputs

Engineering
- fully integrated stand-alone 19“ module
- temperature and humidity stabilized optical compartment
Laser Synchronization

Laser Synchronization Schemes – Comparison

RF
- easy to implement
- low-jitter (<20 fs)
- large drift (hundreds of fs), AM-to-PM

Laser-to-RF
- low-jitter (~3 fs)
- low-drift (<10 fs)
- requires high-power budget
- implementation challenging

Laser-to-Laser
- ultra low-jitter (<1 fs)
- low-drift (<10 fs)
- implementation challenging
Laser Synchronization – RF-based

Based on Conventional RF Synchronization Scheme

Concept

- RF mixing scheme: reference at 1.3 GHz mixed with 1.3 GHz + $f_{\text{rep}}$

- IF signal at $f_{\text{rep}}$ is digitized by fast ADCs (clock derived from reference) and evaluated regarding magnitude/phase

- no DC error signal

  → locking to arbitrary phase set point possible

  → less EMI-related distortions

  → no DC-offset drifts

  → better 1/f noise performance

MicroTCA.4-based controls

- variety of oscillator configurations supported (1 or 2 piezos, motor/piezo stage/temperature tuning, ...)

- dedicated laser sync RTM under development
Laser-to-Laser Synchronization – Concept

Ultra-low Jitter, drift-free Laser-to-Laser Synchronization

- **all-optical scheme** for timing error measurement
  - high accuracy: <100as/mV
  - pure phase-sensitive measurement
  - no drifts due to RF cables etc
- based on **two-color balanced optical cross-correlation**
  - aim: precisely measure the timing error between two pulsed laser sources
  - twofold sum-frequency generation in a non-linear crystal (BBO/PPKTP/PPLN)
  - differential scheme eliminates AM-related influence on the phase measurement
- one **common design** covering requirements of different laser systems
Laser-to-Laser Synchronization

Performance

- laser oscillator: Origami-15
- reference via 3.5 km stabilized fiber link
- PPKTP-based OXC
- **1.3 fs rms in-loop jitter** [10 Hz..10 MHz]
FLASH LbSync Upgrades 2018+
FLASH LbSync Upgrades 2018+

Timeline

Phase 1 (summer 2018)

• **complete removal** of old components (optical table, VME electronics, cabling, …)
• infrastructure installation (new optical table & cover, cabling, rack preparation, MTCA systems, …)
• MLO1 laser lock (RF)
• commissioning of 7 optical links

Phase 2 (summer 2019)

• commissioning of 6 optical links
• MLO2 laser lock (RF)

Phase 3 (summer 2020)

• main rack → MO room
• commissioning of 8 optical links
• **MZM-based** MLO lock
## Optical Links at FLASH

### Timeline: Link Commissioning

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Summer Shutdown 2018

Work in progress...

before...

after 7 weeks of work...
FLASH LbSync Upgrades 2018+
Status & Next Steps

already installed/upgraded

• main distribution system with infrastructure for 12 LSUs
• 7 fiber links in operation: jitter 0.5 fs
• laser synchronization
  • MLO1 RF-based: jitter 17 fs
  • pump-probe laser FLASH1/2: jitter 5 fs

next steps

• fiber links
  • 6 additional links 2019
• laser synchronization
  • MLO2 installation – ongoing
  • injector laser 1 OXC – ongoing
  • FLASH2 THz streaking laser synchronization – ongoing
• PPL: redundant systems for FLASH1 & FLASH2 – Q2/2019
• exchange remaining VME systems by MTCA .4 (FLASH1 seed, THz beamline) – Q2/2019
DOOCS Controls

Before...

After.
Thanks.